Experiences in Flight Mechanics Education: Getting the students hands on the real thing

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Experiences in Flight Mechanics education

Outline

- Introduction
  - Flight Mechanics education @ DIA–PoliMi
  - DIA–PoliMi’s flight activities
  - Didactical experiences

- Development of flight test instrumentation
  - “Mnemosine” system description
  - Validation and testing

- Teaching “Flight Testing”
  - Course presentation
  - The flight test experience
  - Didactical results

- Concluding remarks
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Introduction

Flight Mechanics education @ DIA–PoliMI

- Aeronautical/Aerospace Engineering (AE)
  - Degree (BS, 3 yrs) in Aerospace Engineering
  - Master degree (MS, 2 yrs) in Aeronautical Engineering
  - Doctoral degree (PhD, 3 yrs) in
    - Aerospace Engineering
    - Rotary–wing aircraft (unique in Europe, with AW coop.)
Introduction

Degree (Laurea) in Aerospace Engineering

Main courses concerned at various levels with Flight Mechanics:

- **1st year**
  - *Istituzioni di Ingegneria Aerospaziale*
    - Introduction to Aerospace Engineering

- **2nd year**
  - *Meccanica del Volo* (Basic Flight Mechanics)
  - *Impianti Aerospaziali* (Aerospace Systems & Instrumentation)

- **3rd year**
  - *Costruzioni Aeronautiche* (Airload prediction and Maneuvers)
  - *Sicurezza in Volo* (Flight Safety)
  - *Normative Aeronautiche* (Aeronautical Regulations)
  - *Logistica e Organizzazione del Trasporto Aereo* (Air Transport Management)
Introduction

Master Degree (Laurea Magistrale) in Aerospace Engineering

Main courses concerned at various levels with Flight Mechanics:

• 1st year
  - Meccanica del Volo II
  - Advanced Flight Mechanics

• 2nd year
  - Dinamica e Controllo del Volo
    Flight Dynamics & Control
  - Progetto Generale di Velivoli
    Aircraft Design
  - Progetto di Elicotteri
    Rotorcraft Design
  - Gestione aeroportuale e del Traffico Aereo
    Airport and Air Traffic Management
  - Strumentazione Aeronautica e Aiuti alla Navigazione
    Navigation & Flight Instruments
  - Sperimentazione in Volo
    Flight Testing

POLITECNICO di MILANO – Aerospace Engineering Dept.
Introduction

DIA–PoliMi’s flight activities

- Engagement of DIA–PoliMi in ‘live’ flight activities
  - **Start** in 1995
    - MD–80 operated by Meridiana rented for AE freshmen in-flight experience
    - VLA design and testing (MS thesis)
  - **Acquisition** of Tecnam P–92 in 1998
    - Initial goal: AE freshmen’ familiarization with flight
      - 20’ flight side by side with an instructor pilot
    - Possibility to develop a **flying lab** for
      - Advanced education (MS courses)
      - Applied research (MS thesis, PhD projects)
Introduction

DIA–PoliMi’s flight activities

- Tecnam P92–E80 “Echo”
  Ultra Light Machine, ULM
  - ITA: velivolo ultraleggero
  - JAR–1: Microlight
  - FAA: Light Sport Aircraft, LSA

Definition of a Microlight (Joint Aviation Authorities document JAR–1):
an aeroplane having no more than two seats, maximum stall speed (VS0) of 35 KCAS (65 km/h), and a maximum take–off mass of no more than 450 kg for a landplane, two–seater.

- Aircraft data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wingspan</td>
<td>9.3 m</td>
</tr>
<tr>
<td>Length</td>
<td>6.3 m</td>
</tr>
<tr>
<td>Height</td>
<td>2.5 m</td>
</tr>
<tr>
<td>Wing area</td>
<td>13.2 m²</td>
</tr>
<tr>
<td>Max airspeed @ SL</td>
<td>218 km/h</td>
</tr>
<tr>
<td>Cruise speed @ 75% RPM</td>
<td>190 km/h</td>
</tr>
<tr>
<td>VNE</td>
<td>250 km/h</td>
</tr>
<tr>
<td>Stall speed full flap</td>
<td>61 km/h</td>
</tr>
<tr>
<td>Ceiling</td>
<td>4000 m</td>
</tr>
<tr>
<td>G–load limits</td>
<td>[−3, +6]</td>
</tr>
</tbody>
</table>

- Aircraft operated directly by DIA–PoliMi
  - Based in Baialupo airstrip (45 km from DIA–PoliMi offices)
  - Instructor pilot available for didactic/research activities
  - About 500 flight hours total to date
Introduction

Didactical experiences with DIA-PoliMi’s ULM

• Degree projects
  • Design lab: “New P–92 Air Data System”
    5 students, 4 month work, started spring 2008
    Topics: current ADS characterization; new ADS upgrade requirements, electronic
    package design, implementation, characterization and testing

• Master degree thesis
  • Simone Drera; Analisi teorico sperimentale delle derivate aerodinamiche per un velivolo
    leggero; AA 2002–2003
  • Massimo Landini; Pianificazione ed esecuzione di prove in volo su velivolo leggero in
    funzione dello sviluppo di un simulatore di volo; AA 2004–05
  • Daniele Cilli; Sviluppo ed integrazione di moduli avionici per l’acquisizione dei dati di volo
    che utilizzano il protocollo CANAerospace; AA 2004–2005
  • Enrico Andreano; Un sistema distribuito di acquisizione dati di volo per un velivolo leggero
    basato su CAN bus. Applicazione al Tecnam P92 e confronto con la soluzione analogica; AA
    2004–2005
  • Massimiliano Farina; Sviluppo del nodo di telemetria per un sistema di acquisizione dati
    prove di volo di un velivolo ultraleggero; AA 2005–2006
Introduction

Didactical experiences with DIA–PoliMi’s ULM

• PhD projects
  • Alberto Rolando; Development of an Integrated Flight Test Instrumentation Systems for Ultra Light Machines; XIX ciclo; 2008
    • Design, development and implementation of a low–cost, reliable, easy to manage and maintain, flexible, non intrusive dedicated FTI for the P–92
    • System supporting both research and didactic activities, successfully used in the past 3 years, work still ongoing
    • System permanently installed on the aircraft, without harming non–FTI related activities
    • Considerable growth potential for other ULMs and even small GA aircraft
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• Concluding remarks
Development of flight test instrumentation

- The ULM/LSA, a **striking** commercial success:
  - Thousands of machines currently operated in Europe
  - Over 255 different models available in the Italian market

- **Critical success factors:**
  - “Real” aircraft performances
  - Very low acquisition/operation costs

- **Problem:**
  - No requirements for type certification/airworthiness
  - No systematic flight test activity

- **Hence:**
  - No Flight Testing Instrumentation (FTI) commercial solution available on the market
Development of flight test instrumentation

- Advanced education/research requires **appropriate** FTI
- Possible **research** activities:
  - Aerodynamic and engine modelling and identification
  - Flight and airfield performance determination
  - Flying qualities determination
  - Innovative sensor development and testing
- **Didactical** activities
  - MS course: “Flight testing”
  - BS degree projects, MS thesis, PhD projects
- **Requirements**:
  - General/management (low cost, dependability, simplicity, safety, etc.)
  - Parameter set
  - Aircraft performances
Flight test instrumentation

Establishing requirements

• **Parameter set** requirements
  - Air data (static p, dynamic p, total temp., AoA, AoS) 10 Hz
  - Inertial quantities (velocities and accelerations) 50 Hz
  - Aircraft position & attitude (co-ordinates, attitude angles) 1 Hz
  - Flight controls (stick and pedal position) 10 Hz
  - Engine data (RPM) 1 Hz

• **Aircraft performance**–related requirements:
  - Max altitude 5000 m
  - Max airspeed 400 km/h
  - SL pressure range [90 kPa, 104 kPa]
  - ISA temperature range [-25°, +25°]
  - Load factor range [-10, +10]
  - Propeller RPM range [0, 7500]
Flight test instrumentation

The “Mnemosine” system

**Federated architecture:**
- System subdivided in **autonomous** nodes
  - Each with own processing power, memory, power supply, signal conditioning/interface resources, etc.
  - Intrinsic software partitioning & fault confinement
- **Nodes specialized for a particular task**
  - Customized upon corresponding sensors
- **Distributed installation**
  - Close to sensors for higher data quality
  - Mitigated impact upon aircraft, internal space optimization

Each node communicates on a **common line** (digital data bus)
- Interference resistant, data sharing between nodes, high configuration flexibility

**Disadvantages**
- Some subsystems replicated, weight & volume overhead
- More complex design wrt centralized approach
Flight test instrumentation

“Mnemosine” architecture

IMU
Terpsicore

ADS
Urania

PSU
Melete

RECORDER
Klios

Digital Data Bus

GPS
Polimnia

FC
Eutherpe

ENGINE
Talia

TELEMETRY
Erato

IMU Inertial Measurement Unit
ADS Air Data System
PSU Power Supply Unit
GPS Satellite Positioning
FC Flight Controls
Flight test instrumentation

Data flow

Real-time on-board

- Time stamp at node level
- Storage on a USB removable device
- Raw binary format for min workload & max processing flexibility

Off-line post-processing

- Data processing on a PC
- Conversion into MATLAB format
- Computation:
  - ADS processing
  - GPS/INS integration
  - DGPS augmentation
CAFFE: CAn for Flight Test Equipment

- Variation of CANAerospace, a protocol targeted to avionic systems
  - Many pro’s: robust, efficient, light, good performances, large diffusion
  - But: CANAerospace does not provide built-in data time-stamping

- CAFFE main customized features
  - Different utilization of available bits in the CAN message
  - 2 separate CAN buses – one, the T-bus, dedicated to timing info retrieved from GPS
  - Network Time Synchronization (shared timing info across nodes)
  - Time Tagging (time info association to each datum)

- Ongoing work related to timing issues
  - Time delay resulting from A/D conversion & filtering to be compensated at node level
  - External intelligent sensors (ex. AHRS) “hide” possible internal processing delays – Identification lab tests in order to quantify this effect
Flight test instrumentation
On-board component allocation
Flight test instrumentation
Telemetry system

Motivation:
- Online ground control of the flight test
- Didactical support

Requirements:
- Low cost, free use, range of some km, reasonable bandwidth (100 kBit/s), reliability

Ground station:
- fuzzy logic antenna tracking
- PC based visualization interface

RF data-link:
**DECT** Digital Enhanced Cordless Telephone
- A general radio access technology for wireless communications
- Multi Carrier: 10 frequencies between 1880 and 1900 MHz
- Time Division Multiple Access (TDMA)
- Time Division Duplex (TDD)
A fundamental component: **Trajectory reconstruction algorithm**

- **INS/GPS Sensor fusion by Extended Kalman filter**
  - Uses raw measurements from GPS and INS
  - Tightly coupled scheme
  - 29 state variables involved

- **Highlights:**
  - High accuracy for position, velocity & attitude
  - Robust, high output data rate
  - Output available even during GPS signal outages
Flight test instrumentation

Test flights: Runway fly–by

Track errors

- **Blue line**: solution from raw GPS measurements
- **Red line**: solution from DGPS corrected measurements

- Test data used to tune the EKF
- Very high rate (60 Hz) position & attitude information from low cost sensors
Flight test instrumentation

Test flights: Phugoid

Applicable norm: MIL-F-8785C

$T_{PH} = 10.9 \ s$
$\omega_{PH} = 0.579 \ \text{rad/s}$
$\xi_{PH} = 0.0945$
Flight test instrumentation

Conclusions and Future Developments

- Over 50 flight test missions performed
- Good reliability and performances
- High growth potential (bus load 15%)
- Low impact (permanent installation)

Next:

- Stick force and control surface force measures
- Possible addition of further measures to the Kalman filter
- Migration to other ULM and even GA aircraft:
  - To be used in the testing campaign on the L–19 floatplane focused on load evaluation during landing on water (to validate a numerical model for float design)
  - Possible activity in flight preliminary testing for on-board instrumentation (stand–by display / get–home display)
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Teaching “Flight Testing”

• Presentation
  - A unique characteristic of the MS curriculum in Aeronautical Engineering offered at PoliMi.
  - The course started in academic year 2004–2005
  - Some 50 students took the course so far

• Staff
  - Professor: Paolo Chimetto, Flight Test & Experimental Flight Line Manager, Alenia Aermacchi S.p.A., charged of the Flight Testing activities for the M-346 new lead-in military trainer, one of the world’s most advanced aircrafts.
  - Assistant professor: Giovanni Bonaita, a senior flight testing engineer with a long experience in both fixed and rotary-wing aircrafts, currently consultant to AgustaWestland.
  - The two experts are supplemented by DIA–PoliMi faculty members for general coordination and flight activity support.
Teaching “Flight Testing”

- **Programme and aims**
  - Students are led through the *whole flight testing process*, from requirement analysis, to planning, flight execution, data analysis and reporting
  - Topics encompass all *relevant disciplines*: performance, stability & control, high AoA & spin, air loads & aeroelasticity, on-board systems, and special testing activities
  - Laboratories include planning & organization, flight test preparation, data processing (on campus) as well as *actual flight test execution* (using DIA–PoliMi P-92)

- **Evaluation requirements**
  - Each attending student is required to plan, individually perform and report on a flight test experience, *acting as a Flight Testing Engineer* under all respects. Final evaluation focuses in an oral presentation and discussion based on the flight test report.

- **Flight Test Documentation for Evaluation**
  - **Test Planning**
    Test requirements: objectives, A/C configuration, instrumentation required, flight test conditions and proposed testing techniques & maneuvers, pass/reject criteria, possible constraints and applicable norms & limitations
  - **Test Report**
    Test results: post-processed data presentation and critical discussion, compliance with requirements, comments and conclusions
Teaching “Flight Testing”

The Flight Test Experience

- Typical suggested topics for the flight tests

P–92 endowed with “Mnemosine”, a basic FTI that allows the execution of flight testing tasks in flight performance, flying qualities and qualitative evaluation of some on-board systems.

<table>
<thead>
<tr>
<th>General Topic</th>
<th>Flight maneuver</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Data Calibration</td>
<td>Tower fly By Ground Course</td>
<td>Using GPS</td>
</tr>
<tr>
<td>Flight performances</td>
<td>Take–off (TO), Landing (LND)</td>
<td></td>
</tr>
<tr>
<td>Flight performances</td>
<td>Stalls in 3 configurations (TO, LND, CR)</td>
<td>Using GPS</td>
</tr>
<tr>
<td>Flight performances</td>
<td>Cruise (CR) performances, Vmax</td>
<td></td>
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<tr>
<td>Flight performances</td>
<td>Sawtooth climb</td>
<td></td>
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<tr>
<td>Flying qualities</td>
<td>Static stability in 3 configurations (TO, LND, CR)</td>
<td></td>
</tr>
<tr>
<td>Flying qualities</td>
<td>Longitudinal &amp; lateral–directional dynamic stability</td>
<td></td>
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<tr>
<td>Flying qualities</td>
<td>Maneuvering stability Roll performances</td>
<td></td>
</tr>
<tr>
<td>On–board systems</td>
<td>Radio range</td>
<td></td>
</tr>
</tbody>
</table>

Mnemosine Parameter set
Teaching “Flight Testing”
The Flight Test Experience

• Before flight
The student conceives a specific set of tests to be performed, chosen among the various sub-disciplines involved. Appropriate test cards are produced.

• In flight!
After briefing with the pilot, the student flies through the various test points, verifying the correct execution of the necessary maneuvers and checking hands-on the system behaviour.

• After flight
After de-briefing with the pilot, acquired data are downloaded from the on-board data storage unit and post-processed. A formal document including test planning and test results is produced.
Teaching “Flight Testing”
Didactical results

• The course
  • Looks at the aircraft as complex machine – a system of systems
  • Intrinsically requires multidisciplinary knowledge, leading to a general review, synthesis and verification of acquired notions at the end of the MS curriculum
  • Theory is put side-by-side with practical techniques
  • Has a distinct job-related flavor, albeit retaining academic rigor
  • Qualitative learning: teamwork, use of technical english, reporting ability

• Feedback from students highly positive
  • Flight test experience unique
  • Large degree of initiative relying on the student
  • Contact with top-level experts from industry
  • Some students choose FT-related MS thesis activities, at DIA–PoliMi as well as in Alenia Aermacchi and AgustaWestland
  • Job opportunities in FT have already been exploited
Concluding remarks

• This presentation focused on experiences in Flight Mechanics education involving **in-flight** and **flight-related** activities carried out involving BS, MS and PhD students

• DIA–PoliMi went as far as acquiring and operating a ULM aircraft that has grown up to representing a **flying lab** for advanced education and applied research

• Current projects aim to confirm and **empower** this branch of activities for the near future
  
  • Possible **co-operation** with flying schools, ULM manufacturers, aircraft operators are being considered
  
  • **Tuning** of DIA–PoliMi internal organization concerning flight line management needed to face next challenges